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EFFICIENCY OF A GENERAL PIN PALLET RUNAWAY ESCAPEMENT

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JUNE 1982

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This study developed a technique for evaluating the torque transfer efficiency of a pin pallet runaway escapement. It represents an extension of an earlier effort. The geometry of the escapement has now been generalized and the effects of spin forces are considered. For instance, it is no longer necessary for the pallet pins to be symmetrically located, and the pallet is permitted to have a center of mass which does not coincide with the pivot. In addition, the influence of pivot friction forces is now included.
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20. ABSTRACT (cont)

The formulation of the technique, the computer program, a sample run, and instructions for applying the program are included in this report.

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INTRODUCTION

The pin pallet runaway escapement is commonly employed in fuze Safing and Arming (S&A) mechanisms to provide a safe separation distance for arming. In two earlier reports (references 1 and 2), computer models simulating the motion of devices containing pin pallet escapements were derived to determine arming time. In another report (reference 3), a technique for obtaining the torque transfer efficiency of pin pallet escapements, as well as other kinematic information, was presented. This provided a useful tool for obtaining information to insure that the escapement will start, and that the motion during engagement of the components will be smooth and continuous.

This report represents an extension of the previous work for torque efficiency. The forces generated by a spin field are now considered and the mechanism geometry has been generalized. For example, the center of mass of the pallet can be arbitrarily located, the radii to the two pallet pins do not have to be identical, and the influence of pivot friction is included.

Where necessary for completeness, material from the earlier reports will be repeated in condensed form. In other cases, relevant subject matter will be appropriately referenced.

PIN PALLET RUNAWAY ESCAPEMENT

Description

A schematic diagram of a typical pin pallet runaway escapement is shown in figure 1. This type of escapement consists of the pallet lever, which has two pins attached to it, and the escape wheel, whose teeth alternately engage the pallet pins. The escape wheel is usually connected by a step-up gear train to the component in the fuze system whose motion must be retarded to achieve the desired safe separation distance. A complete description of the operation of the pin pallet runaway escapement is given in reference 1. In this study, it is assumed that a known torque is applied directly to the escape wheel or that a known torque is applied to some element coupled to the escape wheel and the resulting torque exerted on the escape wheel can be computed. The efficiency of this escapement is then obtained by comparing the torque transferred to the pallet lever when friction is considered to that transferred in the absence of friction.

Nomenclature

The two possible geometrical configurations of the escapement pivots relative to the spin center are shown in figure 2. (It is assumed in the analysis which follows that the escape wheel rotates in the counterclockwise direction.) In the figure, C is the spin center and O_S and O_P are the locations of the escape

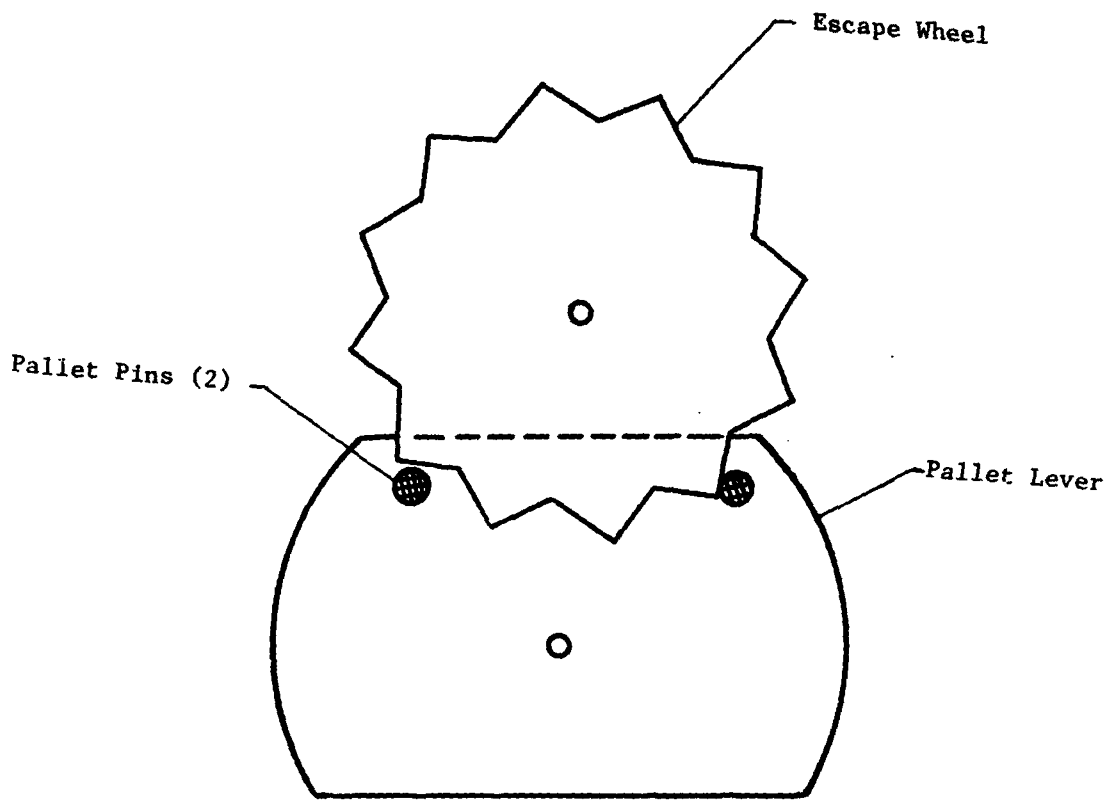
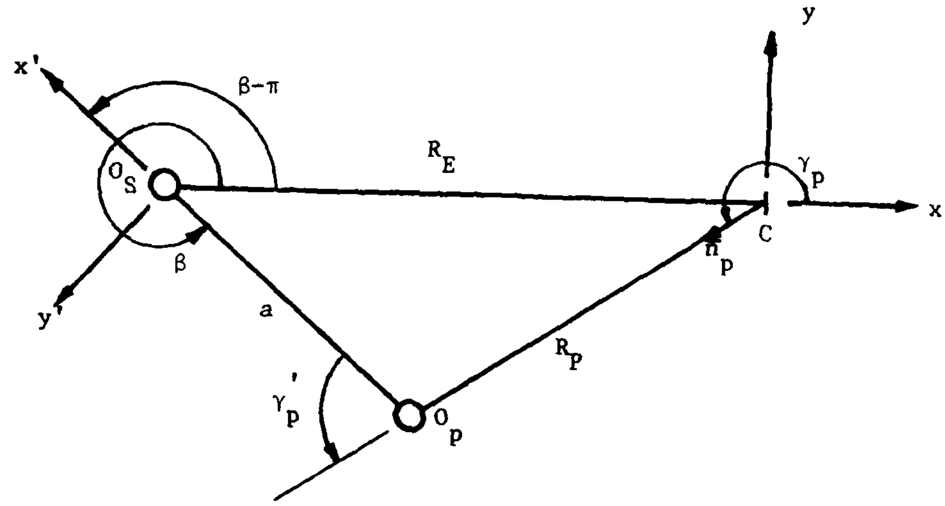
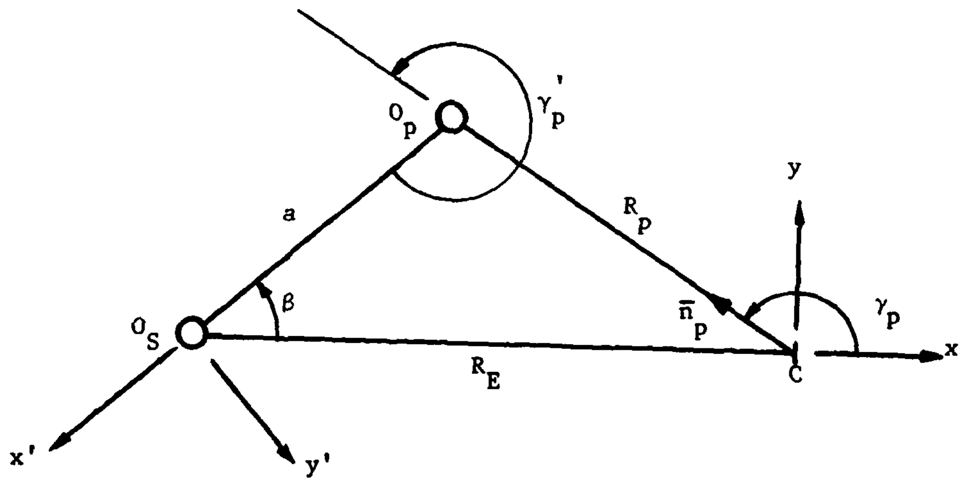


Figure 1. Pin pallet runaway escapement



(a) Configuration no. 1



(b) Configuration no. 2

Figure 2. Escapement pivot configurations with respect to spin center

wheel and pallet pivots, respectively. In addition, the x-y coordinate system is defined so that x is the direction from O_S to C, and the x'-y' coordinate system is defined so that x' is the direction from O_p to O_S. Finally

a = distance between escape wheel and pallet pivots.

R_E = distance between escape wheel pivot and spin center.

R_p = distance between pallet pivot and spin center.

β = angle from line joining O_S and C to line joining O_S and O_p, measured in the counterclockwise direction.

γ_p = angle from x-axis to line joining C and O_p, measured in the counterclockwise direction.

γ_p' = angle from line joining O_S and O_p to line joining O_p and C, measured in the counterclockwise direction.

The kinematic relationship of the escape wheel and pallet when they are in entrance contact is given in figure 3. The following nomenclature is used througout the remainder of this report:

ϕ = escape wheel angle. Defined by the line from the escape wheel pivot O_S to the tip of the contacting tooth, and the line connecting O_S to the pallet pivot O_p.

ψ = pallet angle. Defined by the line from O_p to the active pin center and the line joining the pivots.

b = escape wheel tooth radius

c_{en} = distance from pallet pivot to center of entrance pallet pin.

c_{ex} = distance from pallet pivot to center of exit pallet pin.

r = pallet pin radius.

α = escape wheel tooth half angle.

g = distance from the contact point to the tip of the escape wheel tooth.

Kinematics

Geometry

Referring to figure 1 (a), for configuration no. 1, the angle γ_p can be obtained from the law of cosines as

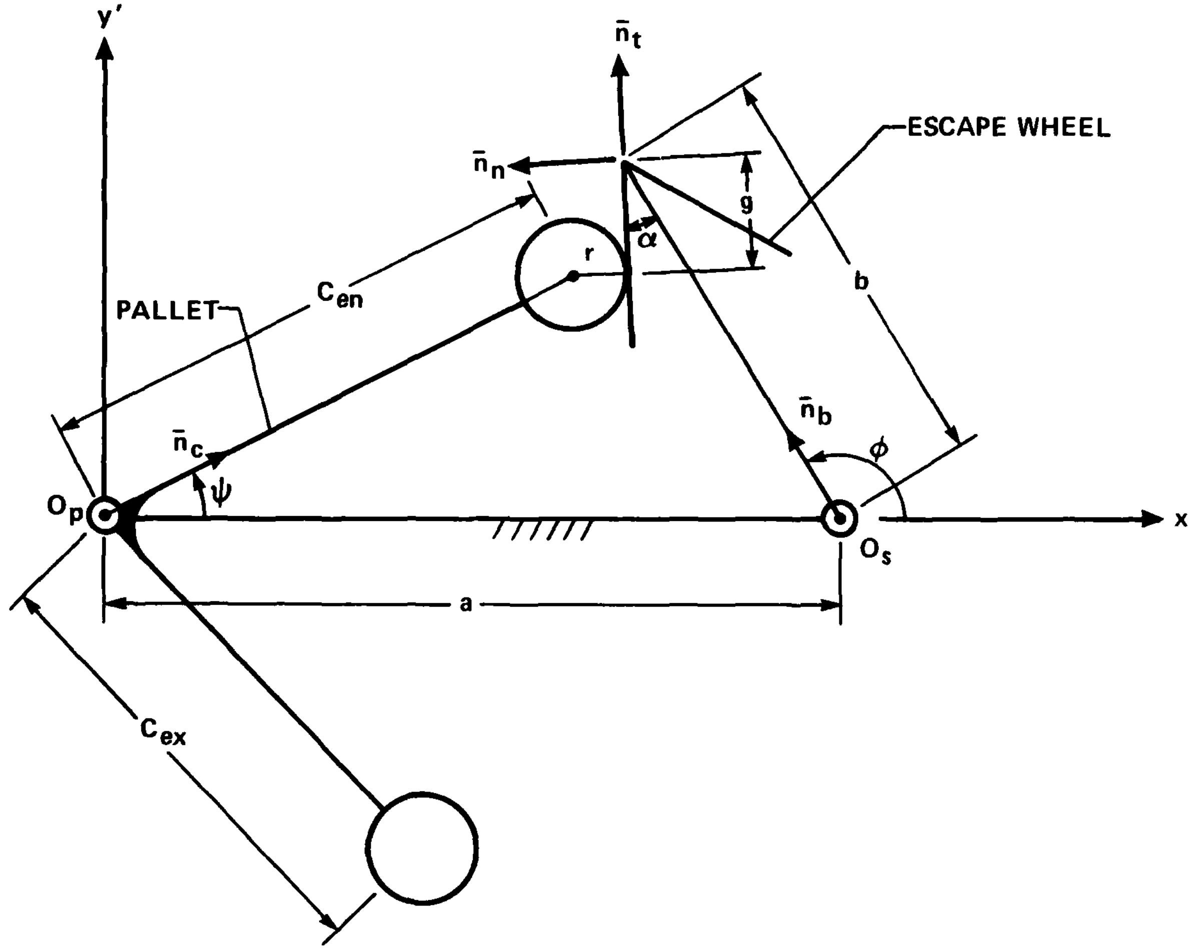


Figure 3. Kinematic relationship of escape wheel and pallet

$$\gamma_p = \cos^{-1}\left(\frac{a^2 - R_E^2 - R_p^2}{2R_E R_p}\right) \tag{1}$$

The angle γ_p must be greater than 180°. Using the law of sines to determine the angle β

$$\beta = \sin^{-1}\left(\frac{R_p \sin \gamma_p}{a}\right) \tag{2}$$

The angle β must be greater than 180°. Finally, the angle γ_p' is given by

$$\gamma_p' = \gamma_p - (\beta - \pi) \tag{3}$$

For configuration no. 2, refer to (b), figure 2. The angles γ_p and β can again be expressed by equations 1 and 2, but now both angles must be less than 180°. For this case, the angle γ_p' becomes

$$\gamma_p' = \gamma_p + \pi - \beta \tag{4}$$

Ranges of Escape Wheel Angles

From references 1 and 2, the minimum values of the escape wheel angle corresponding to entrance and exit motion are obtained from

$$\phi = 2 \tan^{-1}\left[\frac{-L \pm \sqrt{L^2 + M^2 - N^2}}{N-M}\right] \tag{5}$$

where

$$L = 2a\,(g_{max} \sin\alpha - r\cos\alpha) \tag{6}$$

$$M = 2a\,(b + g_{max}\cos\alpha + r\sin\alpha) \tag{7}$$

$$N = g_{max}^2 + b^2 + a^2 + r^2 - c^2 + 2b\,(g_{max}\cos\alpha + r\sin\alpha) \tag{8}$$

$$g_{max} = \left(\frac{b\sin(\delta/2)}{\sin(\pi - \beta)} - \frac{r}{\tan\beta}\right) \tag{9}$$

$$\delta = \frac{360}{n} \tag{10}$$

and n is the number of escape wheel teeth. For the minimum entrance angle, c_{en} is used for c, and the smaller of the two angles resulting from equation 5 is selected. For the minimum exit angle, c_{ex} is used for c, and the larger of the two angles resulting from equation 5 is chosen.

Again from references 1 and 2, the maximum values of the escape wheel angle corresponding to entrance and exit motion are given by

$$\phi = 2\tan^{-1}\left[\frac{-L_o \pm \sqrt{-L_o^2 + M_o^2 - N_o^2}}{N_o - M_o}\right] \tag{11}$$

where

$$L_o = -2ra\cos\alpha \tag{12}$$

$$M_o = 2a\,(r\sin\alpha + b) \tag{13}$$

$$N_o = b^2 + a^2 + r^2 - c^2 + 2br\sin\alpha \tag{14}$$

For the maximum entrance angle, c_{en} is used for c, and the smaller of the two angles resulting from equation 11 is selected. For the maximum exit angle, c_{ex} is used for c, and the larger of the two angles resulting from equation 11 is chosen.

The pallet angle ψ can be written as a function of the escape wheel angle according to equation 7 of reference 3 as

$$\psi = \sin^{-1}\left[\frac{b\sin\phi + g\sin(\phi - \alpha) + r\cos(\phi - \alpha)}{c}\right] \tag{15}$$

DERIVATION OF TORQUE TRANSFER EFFICIENCY EXPRESSION

This section provides a derivation of the expression for the torque transfer efficiency of a pin pallet runaway escapement. The formulation is quasi-static in that it takes into consideration the forces arising from a spin field, but not those originating from the angular acceleration of the pallet or its angular velocity with respect to the spin field. It is applicable to both configurations of figure 2.

Force and Moment Expressions for Pallet

To write both force and moment expressions for the pallet in the x'-y' system, certain relationships between this system, with is oriented along the escapement center line O_pO_S, and the general x-y system are necessary.

The unit vectors $\bar{I}$ and $\bar{J}$ in the x-y system are given in terms of the unit vectors $\bar{I}'$ and $\bar{J}'$ in the x'-y' system by (refer to figure 2)

$$\bar{i} = -\cos\beta\ \bar{i}' + \sin\beta\ \bar{j}' \tag{16}$$

$$\bar{j} = -\sin\beta\ \bar{i}' - \cos\beta\ \bar{j}' \tag{17}$$

The unit vector $\bar{n}_p$ in the direction from the spin center C to the pallet pivot O_p may be expressed in the following manner:

$$\bar{n}_p = \cos\gamma_p'\ \bar{i}' + \sin\gamma_p'\ \bar{j}' \tag{18}$$

With the spin rate ω of the body assumed to be constant, the acceleration of the center of mass of the pallet is given by

$$\bar{A}_{cp} = -\omega^2 R_p\bar{n}_p - \omega^2 r_{cp}[\cos(\psi + \psi_c)\bar{i}' + \sin(\psi + \psi_c)\bar{j}'] \tag{19}$$

When this expression is used in Newton's law for the pallet, whose free body diagram is given in figure 4, the following equation results:

$$\begin{aligned} &P_n\bar{n}_n - \mu_1 P_n\bar{n}_t + F_{xp}'\bar{i}' - \mu_1 sF_{yp}'\bar{i}' + F_{yp}'\bar{j}' + s\mu_1 F_{xp}'\bar{j}' \\ &\quad = m_p\ \{-\omega^2 R_p\bar{n}_p - \omega^2 r_{cp}[\cos(\psi + \psi_c)\bar{i}' + \sin(\psi - \psi_c)\bar{j}' \end{aligned} \tag{20}$$

where

$\bar{n}_t$ and $\bar{n}_n$ are unit vectors along and perpendicular to the contact surface of the escape wheel tooth, respectively, and are given by equations A1 and A2 of reference 1[1] as

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[1] The unprimed coordinate system in reference 1 is equivalent to the primed system of the present report.

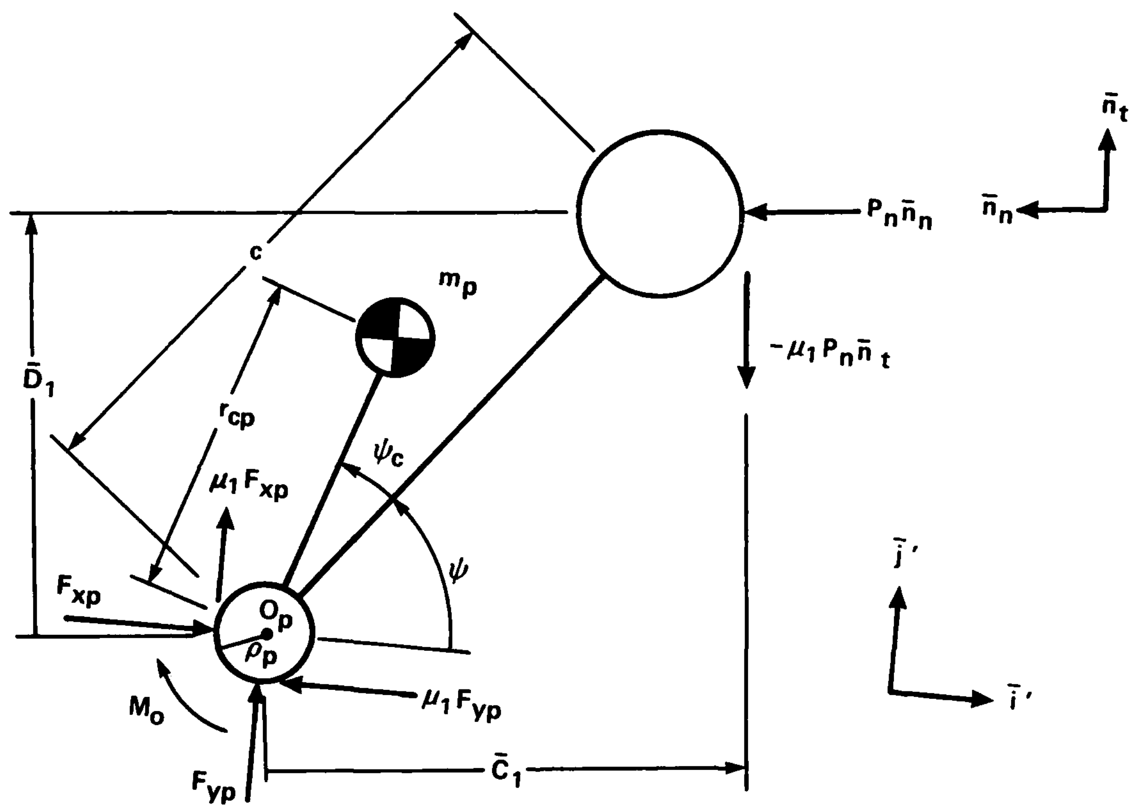

Figure 4. Free body diagram for pallet

$$\bar{n}_t = \cos(\phi - \alpha)\bar{i}' + \sin(\phi - \alpha)\bar{j}' \tag{21}$$

$$\bar{n}_n = -\sin(\phi - \alpha)\bar{i}' + \cos(\phi - \alpha)\bar{j}' \tag{22}$$

In addition, P_n is the interactive force between the escape wheel tooth and the pallet pin, F'_{xp} and F'_{yp} are the x and y components of the pallet pivot force, μ_1 is the coefficient of friction of the pallet pivot and at the escape wheel-pallet interface, m_p is the mass of the pallet, r_{cp} is the distance from the pallet pivot to its center of mass, and ψ_c is the angular location of the pallet center of mass, measured from the line joining the pallet pivot and the entrance pallet pin. Finally, s is a signum function which is defined as

s = 1 when the entrance pallet pin contacts the escape wheel.

s = -1 when the exit pallet pin contacts the escape wheel.

The moment equation of the pallet when written with respect to the pivot O_p becomes

$$\begin{aligned}[-sM_o + P_n(D_1' - C_1'\mu_1) - s\rho_p\mu_1(\tilde{F}_{xp} + \tilde{F}_{yp})]\bar{k} \\ = -(-\omega^2 R_p\bar{n}_p) \times m_p r_{cp}[\cos(\psi + \psi_c)\bar{i}' + \sin(\psi + \psi_c)\bar{j}']\end{aligned} \tag{23}$$

where M_o is the moment required to maintain equilibrium and ρ_p is the pallet pivot radius. As discussed in reference 4, $\tilde{F}_{xp}$ and $\tilde{F}_{yp}$ denote conservatively evaluated pivot force components, and C_1' and D_1' are the friction and normal force moment arms, respectively, with respect to the pallet pivot. Expressions for these moment arms are given in reference 1.

Equation 23 can be rewritten in scalar form as

$$\begin{aligned}-sM_o + P_n(D_1' - C_1'\mu_1) - \rho_p\mu_1 s(\tilde{F}_{xp} + \tilde{F}_{yp}) \\ = \omega^2 R_p m_p r_{cp}\sin(\psi + \psi_c - \gamma_p')\end{aligned} \tag{24}$$

The bearing force components F'_{xp} and F'_{yp} can be obtained by first writing equation 20 in scalar form and then solving for these quantities. Substituting equations 21 and 22 into 20, and separating the resulting equation in x and y components

$$\begin{aligned}-P_n\sin(\phi - \alpha) - \mu_1 P_n\cos(\phi - \alpha) + F'_{xp} - \mu_1 sF'_{yp} \\ = m_p[-\omega^2 R_p\cos\gamma_p' - \omega^2 r_{cp}\cos(\psi + \psi_c)]\end{aligned} \tag{25}$$

$$P_n \cos(\phi - \alpha) - \mu_1 P_n \sin(\phi - \alpha) + F'_{yp} + \mu_1 s F'_{xp}$$
$$= m_p[-\omega^2 R_p \sin\gamma'_p - \omega^2 r_{cp} \sin(\psi + \psi_c)] \tag{26}$$

Simultaneous solution of equations 25 and 26 provides the following expressions for $\tilde{F}_{xp}$ and $\tilde{F}_{yp}$:

$$\tilde{F}_{yp} = P_n A_1 + \omega^2 A_2 \tag{27}$$

$$\tilde{F}_{xp} = P_n A_3 + \omega^2 A_4 \tag{28}$$

where

$$A_1 = \left| \frac{-\cos(\psi - \alpha)(1 + \mu_1^2 s) + \mu_1(1-s)\sin(\psi - \alpha)}{1 + \mu_1^2} \right| \tag{29}$$

$$A_2 = \left| \frac{m_p[R_p(-\sin\gamma'_p + s\mu_1\cos\gamma'_p) + r_{cp}(s\mu_1\cos(\psi + \psi_c) - \sin(\psi + \psi_c))]}{1 + \mu_1^2} \right| \tag{30}$$

$$A_3 = \left| \frac{-\sin(\phi - \alpha)(1 + \mu_1^2 s) + \mu_1(s - 1)\cos(\phi - \alpha)}{1 + \mu_1^2} \right| \tag{31}$$

$$A_4 = \left| \frac{m_p[-R_p(\cos\gamma'_p + \mu_1 s\sin\gamma'_p) - r_{cp}(s\mu_1\sin(\psi + \psi_c) + \cos(\psi + \psi_c))]}{1 + \mu_1^2} \right| \tag{32}$$

With equations 27 and 28, the moment equation now becomes

$$-sM_o + P_n[D'_1 - C'_1 - \mu_1 s\rho_p(A_1 + A_3)]$$
$$= \omega^2[R_p m_p r_{cp} \sin(\psi + \psi_c - \gamma'_p) + \rho_p s\mu_1(A_2 + A_4)] \tag{33}$$

Force and Moment Expressions for Escape Wheel

A free body diagram of the escape wheel is shown in figure 5. The moment equation for the escape wheel is given by

$$-P_n(A_1' + B_1'\mu_1) - \mu\rho_E(\tilde{F}_{xE} + \tilde{F}_{yE}) + M_{in} = 0 \tag{34}$$

where A_1' and B_1' are the moment arms for the normal and friction forces, respectively, with respect to the escape wheel pivot. Expressions for these moment arms are derived in reference 1. The pivot forces $\tilde{F}_{xE}$ and $\tilde{F}_{yE}$ are treated in the manner described in reference 4. Finally, μ is the coefficient of friction at the escape wheel pivot, ρ_E is the radius of the escape wheel pivot, and M_{in} is the input moment exerted on the escape wheel. This moment could be directly applied to the escape wheel (e.g. by a spring) or could be transferred from another component to the escape wheel by means of a gear train. In the latter case, the input moment on the escape wheel would be the moment applied to the other component reduced by the gear ratio.

From Newton's law, the force equation for the escape wheel becomes

$$-P_n\bar{n}_n + \mu_1 P_n\bar{n}_t + F'_{xE}\bar{i}' + \mu F'_{yE}\bar{i}' + \mu F'_{xE}\bar{j}' - F'_{yE}\bar{j}' = m_E R_E \omega^2 \bar{i} \tag{35}$$

where F'_{xE} and F'_{yE} are the x and y components of the escape wheel friction force, and m_E is the mass of the escape wheel. Substituting equations 16, 21, and 22, this expression can be rewritten in component form as

$$P_n\sin(\phi - \alpha) + \mu_1 P_n\cos(\phi - \alpha) + F'_{xE} + \mu F'_{yE} = -m_E R_E \omega^2 \cos\beta \tag{36}$$

$$-P_n\cos(\phi - \alpha) + \mu_1 P_n\sin(\phi - \alpha) + \mu F'_{xE} - F'_{yE} = m_E R_E \omega^2 \sin\beta \tag{37}$$

Simultaneous solution of these two equations gives

$$\tilde{F}_{yE} = P_n A_5 + TA_6 \tag{38}$$

$$\tilde{F}_{xE} = P_n A_7 + TA_8 \tag{39}$$

where

$$A_5 = \left| \frac{-\cos(\phi - \alpha)(1 + \mu\mu_1) + \sin(\phi - \alpha)(\mu_1 - \mu)}{1 + \mu^2} \right| \tag{40}$$

$$A_6 = \left| \frac{\mu\cos\beta + \sin\beta}{1 + \mu^2} \right| \tag{41}$$

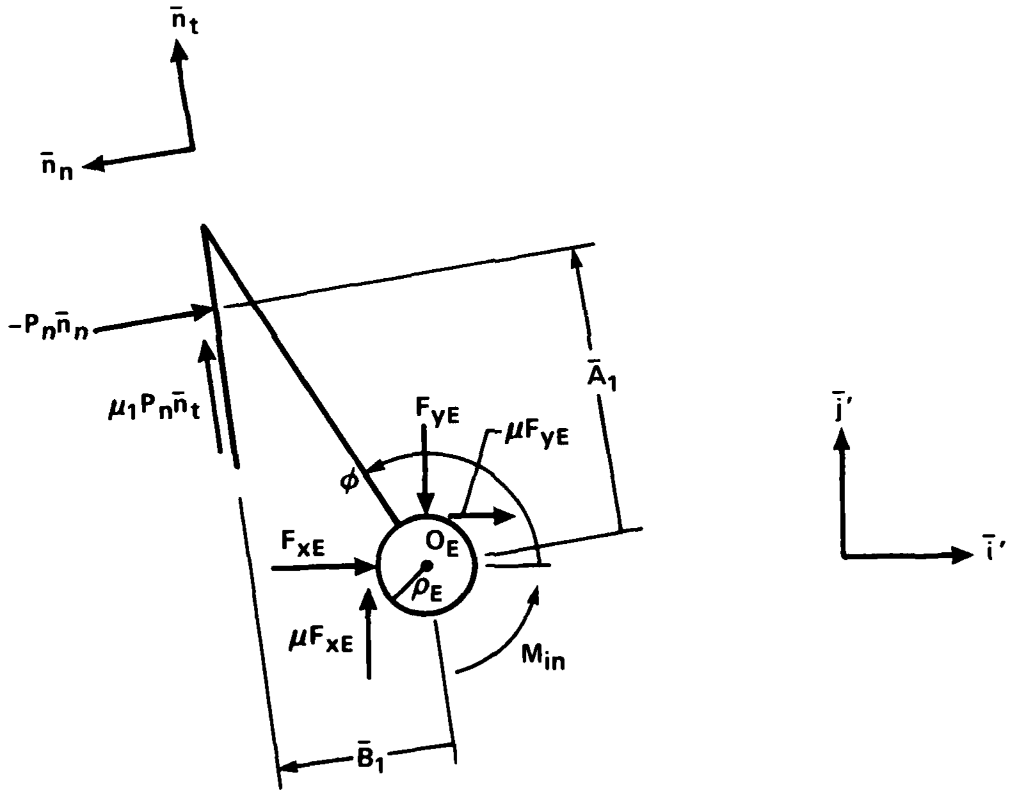

Figure 5. Free body diagram for escape wheel

$$A_7 = \left| \frac{-\sin(\phi - \alpha)(1 + \mu\mu_1) - \cos(\phi - \alpha)(\mu_1 - \mu)}{1 + \mu^2} \right| \tag{42}$$

$$A_8 = \left| \frac{-\cos\beta + \mu\sin\beta}{1 + \mu^2} \right| \tag{43}$$

$$T = m_E R_E \omega^2 \tag{44}$$

Using the above expressions in the moment equation leads to the following relationship:

$$-P_n(A_1' + B_1'\mu_1) - \mu\rho_E[P_n(A_5 + A_7) + T(A_6 + A_8)] + M_{in} = 0 \tag{45}$$

Torque Transfer Efficiency

To obtain a combined equation for the pallet and escape wheel, solve equations 33 and 45 for the contact force P_n, and set the resulting equations equal to each other. Thus

$$\frac{M_{in} - \mu\rho_E T(A_6+A_8)}{A_1'+B_1'\mu_1+\mu\rho_E(A_5+A_7)} = \frac{sM_o+\omega^2[R_p m_p r_{cp}\sin(\psi+\psi_c-\gamma_p')+\rho_p s\mu_1(A_2+A_4)]}{D_1'-\mu_1[C_1'+\rho_p s(A_1+A_3)]} \tag{46}$$

This can be written in simplified form as

$$M_o = M_{in}A_9 - A_9A_{10} + A_{11} \tag{47}$$

where

$$A_9 = \frac{D_1' - \mu_1[C_1' + \rho_p s(A_1 + A_3)]}{s[A_1' + \mu_1 B_1' + \mu\rho_E(A_5 + A_7)]} \tag{48}$$

$$A_{10} = \mu\rho_E T(A_6 + A_8) \tag{49}$$

$$A_{11} = \frac{-\omega^2}{s}[R_p m_p r_{cp}\sin(\psi + \psi_c - \gamma_p') + \rho_p s\mu_1(A_2 + A_4)] \tag{50}$$

In the absence of friction, the output moment can be called the "ideal" output moment. With the help of equation 47, it is given by

$$M_{oi} = sM_{in}A_{12} + A_{13} \tag{51}$$

where

$$A_{12} = \frac{D_1'}{A_1'} \tag{52}$$

$$A_{13} = \frac{-\omega^2}{s} R_p m_p r_{cp} \sin(\psi + \psi_c - \gamma_p') \tag{53}$$

The escapement efficiency is therefore given by

$$\varepsilon = \frac{M_o}{M_{oi}} = \frac{M_{in}A_9 - A_9A_{10} + A_{11}}{sM_{in}A_{12} + A_{13}} \tag{54}$$

DESCRIPTION OF COMPUTER PROGRAM

A listing of the FORTRAN computer program developed to perform the efficiency computations is given in the appendix. The program initially places the escapement in the starting position for the entrance half cycle [that is, ϕ corresponds to $g = g_{max}$ (fig. 3)]. It does this by calling on the subroutine ANGLES to find the minimum and maximum values of ϕ for both entrance and exit motion. For entrance motion, equations 5 and 11 are used with $c = c_{en}$, and for exit motion, the same equations are used with $c = c_{ex}$. The program then identifies which configuration type is being considered and computes the appropriate geometry (equations 1 through 4) associated with it. Following this, the pallet angle ψ and the moment arms A_1', B_1', C_1', and D_1' are calculated in subroutine KINEM using equation 15 from this report and equations C4 through C7 of reference 1. The efficiency of the escapement in the given position is then determined by subroutine COMP using equation 54. After the efficiency has been obtained, the position of the escape wheel is indexed by 0.01 radians, and the calculations are repeated for this new position. This process continues until the entrance half cycle is completed [that is, the angle ϕ corresponds to $g = 0$ (fig. 3)]. The escapement is then placed in the starting position for the exit phase, and the above procedure is repeated for the entire range of exit positions.

DETERMINATION OF EXAMPLE MECHANISM EFFICIENCY

Refer to the appendix for both the computer variables and the symbols given in this report. The safe separation device of the M577 fuze will be used as an example mechanism. The data requirements for the computer program are as follows:

A = a = 0.2097 in. (0.5326 cm) = distance between pivots O_p and O_S

B = b = 0.1930 in. (0.4902 cm) = escape wheel radius

CEN = c_{en} = 0.0788 in. (0.2002 cm) = entrance pallet radius from pivot to center of pin

R = r = 0.015 in. (0.0381 cm) = pallet pin radius (identical for entrance and exit)

ALPHA = α = 52° = escape wheel tooth half angle

LAMBDA = λ = 152.144° = angle between entrance and exit pallet radii

RE = R_E = 0.3680 in. (0.9347 cm) = distance of pivot of escape wheel from spin axis

RP = R_p = 0.3610 in. (0.9169 cm) = distance of pivot of pallet from spin axis

ME = m_E = 2.656 x 10^{-6} lb-sec^2/in. (2.255 x 10^{-9} kg) = mass of escape wheel

MP = m_p = 2.451 x 10^{-6} lb-sec^2/in. (2.086 x 10^{-9} kg) = mass of pallet

RCP = r_{cp} = 0. = pallet eccentricity

PSICC = ψ_C = 0° = eccentricity angle of pallet (fig. 4)

RHOE = ρ_E = 0.0155 in. (0.03937 cm) = escape wheel pivot radius

RHOP = ρ_p = 0.0155 in. (0.03937 cm) = pallet pivot radius

MU = μ = 0.1 = coefficient of friction of escape wheel pivot

MU1 = μ_1 = 0.1 = coefficient of friction on pallet-escape wheel interface and pallet pivot

RPM = 5,000 = spin rate

MD = 0.2766 x 10^{-7} in-lb-sec^2 (1.519 kg-cm^2) = "mass-distance"[2] product for escape wheel input driving moment

CONFIGURATION = 2 = type of escapement configuration

The program then prints the angles GAMMAP = γ_p, BETAD = β, and GAMAPP = γ'_p for checking purposes.

For each position of the escape wheel PHID = ϕ, the program lists the corresponding value of the pallet position PSID = ψ, and the torque transfer efficiency EFF = ε for the escapement. From the results in the appendix for the conditions of the sample mechanism, the minimum value of the efficiency, EFF = 0.605 occurs at the initial contact position during entrance motion. It continuously increases until it reaches 0.630 at the final entrance position. At the initial contact position for the exit phase of motion, EFF = 0.685. The efficiency then increases to a maximum of 0.686 before decreasing to 0.641 at the final exit position.

CONCLUSIONS

A previously developed technique has been extended to evaluate the torque transfer efficiency of a pin pallet runaway escapement. It is now possible to analyze such an escapement considering the effects of spin, pivot friction forces, a center of mass which does not coincide with the pallet shaft, and pallet pins which are not symmetrically located. The generalized analytic tool can be used as a guide in the design of new pin pallet escapements or in the improvement of existing escapements.

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[2] The driving torque exerted on a spin driven rotor is given by $m_R r_{CR} R_R \omega^2$, where m_R is the mass of the rotor, r_{CR} is the distance from the rotor pivot to its center of mass, and R_R is the distance of the rotor pivot from the spin center. The "mass-distance" product MD is $m_R r_{CR} R_R/GR$, where GR is the gear train ratio.

REFERENCES

1. Gerard G. Lowen and Frederick R. Tepper, "Dynamics of the Pin Pallet Runaway Escapement," Technical Report ARLCD-TR-77062, ARRADCOM, Dover, NJ, June 1978.

2. Gerard G. Lowen and Frederick R. Tepper, "Computer Simulations of Artillery S&A Mechanisms (Involute Gear Train and Pin Pallet Runaway Escapement)," Technical Report ARLCD-TR-81039, ARRADCOM, Dover, NJ, (in press).

3. Chris W. Janow and Frederick R. Tepper, "Derivation of the Kinematic Properties of the Pin Pallet Runaway Escapement," Technical Report ARLCD-TR-79019, ARRADCOM, Dover, NJ, October 1979.

4. Gerard G. Lowen and Frederick R. Tepper, "Fuze Gear Train Analysis," Technical Report ARLCD-TR-79030, ARRADCOM, Dover, NJ, December 1979.

APPENDIX

COMPUTER PROGRAM FOR DETERMINING PIN PALLET RUNAWAY ESCAPEMENT TORQUE TRANSFER EFFICIENCY AND SAMPLE RESULTS

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```
      PROGRAM PINPAL(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
      REAL LAMBDA,ME,MP,MU,MU1,MIN,MD
    1 READ(5,2)A,B,CEN,CEX,R,ALPHA,LAMBDA,DELTA,RE,RP,ME,MP,RCP,PSICC,
     2RHOE,RHOP,MU,MU1,RPM,MD,CONFIG
      IF(EOF(5).NE.0)STOP
    2 FORMAT(8F10.4/2F10.4/2E10.4/7F10.4/E10.4/F10.4)
      WRITE(6,3)A,B,CEN,CEX,R,ALPHA,LAMBDA,DELTA,RE,RP,ME,MP,RCP,PSICC,
     1RHOE,RHOP,MU,MU1,RPM,MD,CONFIG
    3 FORMAT(*1A =*,F6.4,3X,*B =*,F6.4,3X,*CEN =*,F6.4,3X,*CEX =*,F6.4,
     13X,*R =*,F6.4/* ALPHA =*,F6.2,3X,*LAMBDA =*,F8.3,3X,*DELTA =*,
     2F6.2/* RE =*,F6.4,3X,*RP =*,F6.4/* ME =*,E12.4,3X,*MP =*,E12.4/
     3* RCP =*,F6.4,3X,*PSICC =*,F7.2,3X,*RHOE =*,F6.4,3X,*RHOP =*,F6.4/
     4* MU =*,F4.2,3X,*MU1 =*,F4.2,3X,*RPM =*,F7.0/* MD =*,E12.4/* CONFI
     5GURATION =*,F3.1//)
      PI=3.14159
      TWOPI=2.*PI
      Z=PI/180.
      ALPHA=ALPHA*Z
      LAMBDA=LAMBDA*Z
      DELTA=DELTA*Z
      OM=RPM*TWOPI/60.
      OM2=OM*OM
      CALL ANGLES(PI,A,B,CEN,CEX,R,ALPHA,DELTA,PHIENI,PHIENF,PHIEXI,
     1PHIEXF)
      T=ME*RE*OM2
      MIN=MD*OM2
      IF(CONFIG.EQ.2.)GO TO 4
      GAMMAP=ACOS((A*A-RE*RE-RP*RP)/(2.*RE*RP))
      GAMMAP=TWOPI-GAMMAP
      BETA=ASIN(RP*SIN(GAMMAP)/A)+TWOPI
      GAMAPP=GAMMAP-(BETA-PI)
      GO TO 5
    4 GAMMAP=ACOS((A*A-RE*RE-RP*RP)/(2.*RE*RP))
      BETA=ASIN(RP*SIN(GAMMAP)/A)
      GAMAPP=PI-BETA+GAMMAP
    5 GAMMAPD=GAMMAP/Z
      BETAD=BETA/Z
      GAMAPPD=GAMAPP/Z
      WRITE(6,11)GAMMAPD,BETAD,GAMAPPD
   11 FORMAT(* GAMMAP =*,F7.2,3X,*BETAD =*,F7.2,3X,*GAMAPP =*,F7.2//)
C
C     ENTRANCE
C
      PHI=PHIENI
      S=1.
      PSIC=PSICC
    6 IF(PHI.GT.PHIENF)GO TO 8
      CALL KINEM(A,B,CEN,R,ALPHA,PHI,PSI,A1,B1,C1,D1)
      CALL COMP(A,B,CEN,R,ALPHA,PHI,PSI,A1,B1,C1,D1,ME,MP,RE,RP,RHOE,
     1RHOP,S,MU,MU1,GAMAPP,RCP,PSIC,BETA,T,OM2,MIN,CONFIG,EFF)
      PHID=PHI/Z
      PSID=PSI/Z
      WRITE(6,7)PHID,PSID,EFF
    7 FORMAT(* PHID =*,F8.3,3X,*PSID =*,F8.3,3X,*EFF =*,F6.3)
      PHI=PHI+.01
      GO TO 6
C
```

```
C  EXIT
C
     8 PHI=PHIEXI
     9 IF(PHI.GT.PHIEXF)GO TO 10
       S=-1.
       PSIC=PSICC+LAMBDA
       CALL KINEM(A,B,CEX,R,ALPHA,PHI,PSI,A1,B1,C1,D1)
       CALL COMP(A,B,CEX,R,ALPHA,PHI,PSI,A1,B1,C1,D1,ME,MP,RE,RP,RHOE,
      1RHOP,S,MU,MU1,GAMAPP,RCP,PSIC,BETA,T,OM2,MIN,CONFIG,EFF)
       PHID=PHI/Z
       PSID=PSI/Z
       WRITE(6,7)PHID,PSID,EFF
       PHI=PHI+.01
       GO TO 9
    10 GO TO 1
       END
```

```
      SUBROUTINE KINEM(A,B,C,R,ALPHA,PHI,PSI,A1,B1,C1,D1)
      REAL K
      H=2.*(B*COS(ALPHA)+A*COS(PHI-ALPHA))
      K=A**2+B**2+R**2-C**2+2.*B*R*SIN(ALPHA)+2.*A*B*COS(PHI)
     1-2.*A*R*SIN(PHI-ALPHA)
      G1=(-H+SQRT(H**2-4.*K))/2.
      G2=(-H-SQRT(H**2-4.*K))/2.
      IF(ABS(G1).LT.ABS(G2))GO TO 1
      G=G2
      GO TO 2
    1 G=G1
    2 P=B*SIN(PHI)+G*SIN(PHI-ALPHA)+R*COS(PHI-ALPHA)
      PSI=ASIN(P/C)
      IF(PSI.LT.0.)GO TO 3
      GO TO 4
    3 PSI=2.*3.14159-ABS(PSI)
    4 A1=B*COS(ALPHA)+G
      B1=B*SIN(ALPHA)
      C1=R+C*SIN(PHI-ALPHA-PSI)
      D1=C*COS(PHI-ALPHA-PSI)
      RETURN
      END
```

```
      SUBROUTINE ANGLES(PI,A,B,CEN,CEX,R,ALPHA,DELTA,PHIENI,PHIENF,
     1PHIEXI,PHIEXF)
      REAL L,M,NEX,NEN,LO,MO,NOEN,NOEX
      BETA=ALPHA+DELTA/2.
      ST=B*SIN(DELTA/2.)/SIN(PI-BETA)
      GMAX=R/TAN(BETA)-ST
      L=2.*A*(GMAX*SIN(ALPHA)-R*COS(ALPHA))
      M=2.*A*(GMAX*COS(ALPHA)+B+R*SIN(ALPHA))
      NEN=GMAX**2+A*A+B*B+R*R-CEN*CEN+2.*B*(GMAX*COS(ALPHA)+R*SIN(ALPHA)
     1)
      NEX=GMAX**2+A*A+B*B+R*R-CEX*CEX+2.*B*(GMAX*COS(ALPHA)+R*SIN(ALPHA)
     1)
      ROOT1EN=SQRT(L*L-NEN*NEN+M*M)
      ROOT1EX=SQRT(L*L-NEX*NEX+M*M)
      PHIEN1=2.*ATAN2(-L+ROOT1EN,NEN-M)
      PHIEN2=2.*ATAN2(-L-ROOT1EN,NEN-M)
      PHIEX1=2.*ATAN2(-L+ROOT1EX,NEX-M)
      PHIEX2=2.*ATAN2(-L-ROOT1EX,NEX-M)
      TWOPI=2.*PI
      IF(PHIEN1.LT.0.)PHIEN1=PHIEN1+TWOPI
      IF(PHIEN2.LT.0.)PHIEN2=PHIEN2+TWOPI
      IF(PHIEX1.LT.0.)PHIEX1=PHIEX1+TWOPI
      IF(PHIEX2.LT.0.)PHIEX2=PHIEX2+TWOPI
      IF(PHIEN1.LE.PHIEN2)PHIENI=PHIEN1
      IF(PHIEN2.LE.PHIEN1)PHIENI=PHIEN2
      IF(PHIEX1.GE.PHIEX2)PHIEXI=PHIEX1
      IF(PHIEX2.GE.PHIEX1)PHIEXI=PHIEX2
      LO=-2.*A*R*COS(ALPHA)
      MO=2.*A*(B+R*SIN(ALPHA))
      NOEN=A*A+B*B+R*R-CEN*CEN+2.*B*R*SIN(ALPHA)
      NOEX=A*A+B*B+R*R-CEN*CEX+2.*B*R*SIN(ALPHA)
      ROOT2EN=SQRT(LO*LO-NOEN*NOEN+MO*MO)
      ROOT2EX=SQRT(LO*LO-NOEX*NOEX+MO*MO)
      PHIEN3=2.*ATAN2(-LO+ROOT2EN,NOEN-MO)
      PHIEN4=2.*ATAN2(-LO-ROOT2EN,NOEN-MO)
      PHIEX3=2.*ATAN2(-LO+ROOT2EX,NOEX-MO)
      PHIEX4=2.*ATAN2(-LO-ROOT2EX,NOEX-MO)
      IF(PHIEN3.LT.0.)PHIEN3=PHIEN3+TWOPI
      IF(PHIEN4.LT.0.)PHIEN4=PHIEN4+TWOPI
      IF(PHIEX3.LT.0.)PHIEX3=PHIEX3+TWOPI
      IF(PHIEX4.LT.0.)PHIEX4=PHIEX4+TWOPI
      IF(PHIEN3.LE.PHIEN4)PHIENF=PHIEN3
      IF(PHIEN4.LE.PHIEN3)PHIENF=PHIEN4
      IF(PHIEX3.GE.PHIEX4)PHIEXF=PHIEX3
      IF(PHIEX4.GE.PHIEX3)PHIEXF=PHIEX4
      RETURN
      END
```

```
      SUBROUTINE COMP(A,B,C,R,ALPHA,PHI,PSI,A1,B1,C1,D1,ME,MP,RE,RP,
     1RHOE,RHOP,S,MU,MU1,GAMAPP,RCP,PSIC,BETA,T,OM2,MIN,CONFIG,EFF)
      REAL ME,MP,MU,MU1,MIN,MD
      DENOM=1.+MU**2
      DENOM1=1.+MU1**2
      AA1=ABS((-COS(PHI-ALPHA)*(1.*MU1*MU1*S)+MU1*(1.-S)*SIN(PHI-ALPHA))
     1/DENOM1)
      AA2=ABS(MP*(RP*(-SIN(GAMAPP)+S*MU1*COS(GAMAPP))+RCP*(S*MU1*COS(PSI
     1+PSIC)-SIN(PSI+PSIC)))/DENOM1)
      AA3=ABS((-SIN(PHI-ALPHA)*(1.+MU1*MU1*S)+MU1*(S-1.)*COS(PHI-ALPHA))
     1/DENOM1)
      AA4=ABS(MP*(-RP*(COS(GAMAPP)+MU1*S*SIN(GAMAPP))-RCP*(MU1*S*SIN(PSI
     1+PSIC)+COS(PSI+PSIC)))/DENOM1)
      AA5=ABS((-COS(PHI-ALPHA)*(1.+MU*MU1)+SIN(PHI-ALPHA)*(MU1-MU))/
     1DENOM)
      AA6=ABS((MU*COS(BETA)+SIN(BETA))/DENOM)
      AA7=ABS((-SIN(PHI-ALPHA)*(1.+MU*MU1)-COS(PHI-ALPHA)*(MU1-MU))/
     1DENOM)
      AA8=ABS((-COS(BETA)+MU*SIN(BETA))/DENOM)
      AA9=(D1-MU1*(C1+RHOP*S*(AA1+AA3)))/((A1+MU1*B1+MU*RHOE*(AA5+AA7))
     1*S)
      AA10=MU*RHOE*T*(AA6+AA8)
      AA11=-OM2*(RP*MP*RCP*SIN(PSI+PSIC-GAMAPP)+RHOP*S*MU1*(AA2+AA4))/S
      AA12=D1/A1
      AA13=-OM2*RP*MP*RCP*SIN(PSI+PSIC-GAMAPP)/S
      EFF=(MIN*AA9-AA9*AA10+AA11)/(S*MIN*AA12+AA13)
      RETURN
      END
```

```
A = .2097   B = .1950   CEN = .0788   CEX = .0788   R = .0150
ALPHA = 52.00   LAMBDA = 152.144   DELTA = 30.00
RE = .3680   RP = .3610
ME =   .2656E-05   MP =   .2451E-05
RCP =0.0000   PSICC =   0.00   RHCE = .0155   RHOP = .0155MU = .20   MU1 = .20   RPM =  5000.
MO =   .2766E-07
CONFIGURATION =2.0


GAMMAP = 146.58   BETAD =  71.46   GAMAPP = 255.12


PHID = 143.259   PSID =  58.565   EFF =  .326
PHID = 143.832   PSID =  59.187   EFF =  .327
PHID = 144.405   PSID =  59.827   EFF =  .327
PHID = 144.978   PSID =  60.485   EFF =  .327
PHID = 145.551   PSID =  61.161   EFF =  .327
PHID = 146.124   PSID =  61.855   EFF =  .327
PHID = 146.697   PSID =  62.566   EFF =  .328
PHID = 147.270   PSID =  63.295   EFF =  .328
PHID = 147.843   PSID =  64.042   EFF =  .328
PHID = 148.416   PSID =  64.806   EFF =  .328
PHID = 148.989   PSID =  65.588   EFF =  .328
PHID = 149.561   PSID =  66.387   EFF =  .328
PHID = 150.134   PSID =  67.203   EFF =  .328
PHID = 150.707   PSID =  68.036   EFF =  .328
PHID = 151.280   PSID =  68.886   EFF =  .328
PHID = 151.853   PSID =  69.752   EFF =  .329
PHID = 152.426   PSID =  70.635   EFF =  .329
PHID = 152.999   PSID =  71.534   EFF =  .329
PHID = 153.572   PSID =  72.449   EFF =  .329
PHID = 154.145   PSID =  73.380   EFF =  .329
PHID = 154.718   PSID =  74.326   EFF =  .330
PHID = 155.291   PSID =  75.289   EFF =  .330
PHID = 186.741   PSID = 301.434   EFF =  .475
PHID = 187.314   PSID = 300.896   EFF =  .475
PHID = 187.887   PSID = 300.341   EFF =  .474
PHID = 188.460   PSID = 299.769   EFF =  .473
PHID = 189.033   PSID = 299.179   EFF =  .472
PHID = 189.606   PSID = 298.571   EFF =  .471
PHID = 190.179   PSID = 297.943   EFF =  .469
PHID = 190.752   PSID = 297.294   EFF =  .467
PHID = 191.325   PSID = 296.625   EFF =  .464
PHID = 191.898   PSID = 295.933   EFF =  .461
PHID = 192.471   PSID = 295.218   EFF =  .458
PHID = 193.044   PSID = 294.478   EFF =  .454
PHID = 193.617   PSID = 293.712   EFF =  .449
PHID = 194.190   PSID = 292.918   EFF =  .444
PHID = 194.763   PSID = 292.095   EFF =  .439
PHID = 195.335   PSID = 291.241   EFF =  .433
PHID = 195.908   PSID = 290.353   EFF =  .426
PHID = 196.481   PSID = 289.429   EFF =  .418
PHID = 197.054   PSID = 288.466   EFF =  .409
PHID = 197.627   PSID = 287.461   EFF =  .400
PHID = 198.200   PSID = 286.409   EFF =  .389
PHID = 198.773   PSID = 285.307   EFF =  .376
```

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